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TECHNICAL REPORT FRL-TR-57

METHOD FOR OBTAINING PRECISE VELOCITIES OF RAPIDLY MOVING FRAGMENTS

FRANK R. SCHWARTZ

APRIL 1962

FELTMAN RESEARCH LABORATORIES
PICATINNY ARSENAL
DOVER, N. J.

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by

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ABSTRACT

An experimental technique is described by which the velocities of small masses can be precisely determined with an ultra-high-speed (rotating mirror) framing camera. Intentional double exposure of the film by rewriting affords multiple records of the projectile in flight, each frame being an individual record with an accuracy limited by the operating characteristics of the camera. (Time resolution depends upon mirror speed.)

CONCLUSION

The technique described herein is of value in the precise determination of the velocities of fragments whose geometry is known or whose center of mass can be estimated. This method is appropriate for the study of luminous (hypervelocity) or nonluminous fragments whose trajectories can be predicted. The time resolution of the framing camera at its highest operating speed is 0.02%.

INTRODUCTION

The simplest procedure for determining the velocity of a projectile in flight by photographic means is to use a single exposure camera and obtain some form of multiple exposure of the event against a calibrated scale. This can be accomplished by using successive flashes from a high-intensity light source. Further refinements of this technique make use of multiple flashes and associated optics to give separate time-displaced frames of the event. Electro-optical shutters can be used in a similar manner, the shutter being pulsed instead of the light source to give the same results. In all the above methods, the accuracy with which the average velocity during the recording interval can be determined depends upon the least precise determination of either position or time. Moreover, even with successive high-intensity flashes of short duration, and with precise interval timers or time delay generators, it is difficult to obtain time resolutions of the order of a microsecond. However, if the distances of travel and the times involved are long, determinations of the average velocities of projectiles in flight can be made with a high relative accuracy.

Ordinarily the study of large masses in flight can be readily accomplished by well-established techniques for ballistic study. As the size of the projectile is reduced and the velocity increased, the standard techniques can still be used, but only at the expense of some loss in accuracy. If, in addition, account must be taken of some randomness in flight, this poses an added restriction as to the type and position of the sensing or recording elements. The sensing grids or coils used in exterior ballistic study are usually relatively massive elements which must be spaced far apart to reduce the inherent error of these devices.

During an investigation into the relative energies of explosives and their ability to accelerate metal fragments, the need arose for a precise method of obtaining plate velocities. The high-speed rotating-mirror framing camera is an excellent tool for the study of high speed phenomena and has been used for determining the velocity of fragments. However, it was decided that this instrument would yield more precise data if it was operated in a slightly modified way. Accordingly, the system described in this report was developed and is being used.

DISCUSSION

The camera used for this study was the Beckman Whitley Model No. 189 camera, which is the commercial model of the Bowen RC-4 type rotating-mirror framing camera. The optical system of this camera consists of an objective lens, a field lens, and a rotating mirror which is driven by an air turbine at speeds up to 5000 rps. The event which is imaged on the rotating mirror is swept by the mirror through 25 complete sets of relay lenses and imaged as 25 separate frames on a strip of 35 mm film positioned at the periphery of a circle with the axis of the mirror at its center.

The objective lens supplied with this camera is a simple air-spaced achromat with a focal length of 24 inches. The camera has a minimum focusing distance of 8 feet and an effective aperture of f14. Because of the space limitations of the firing chamber, the maximum distance of the camera from the event was 14 feet; at this distance, the field covered by the camera was approximately 6 inches in the direction of flight. To improve the versatility of the camera, the optical system was modified to accommodate lenses of different focal lengths. The objective lens was replaced by a relay lens system consisting of a 24½-inch cemented achromat and a 7-inch f2.5 Aero-Ektar lens barrel-mounted in the camera objective housing with the longer focal length lens closest to the rotating mirror. This arrangement was such that any real image formed at the focus of the 7-inch lens was relayed onto the film plane. Thus a single lens mount with adaptors for lenses of various focal lengths could be used to form the aerial image for the above assembly. The present study was made using a 3-inch f2.3 Balter lens, the effective aperture of the system being f16. At 14 feet from the camera, the present optical system covers approximately 15 inches of target area.

Ordinarily, in photographing an event, the framing camera gives a burst of 25 frames whose total framing time covers 20 microseconds at 5000 rps with approximately 0.3 microsecond exposure per frame. For pellets in flight this 0.3 microsecond represents also the space-time movement of the pellet in flight, which can be assumed to be the same from frame to frame. However, the time between frames is not uniform throughout the film and thus a correction factor must be applied which depends on the geometry of the individual camera. This correction factor must be applied if some degree of precision is to be obtained.

For objects moving at high velocity, wherein the displacement is known to be 0.1% or better, the calibrated camera method could be used to obtain velocities with a maximum accuracy of 0.1%.

In the present study, it was found that, when the framing camera is used in an intentional rewriting manner, the movement of the event over long distances and through a time element of at least 200 microseconds gives multiple records of high accuracy which can be checked from frame to frame, the space movement of the object on each frame being identical (assuming uniform velocity).

The manner in which the rewrite technique can be used to give accuracies to 0.1% or better can readily be understood from the following considerations: For objects moving at moderate speeds up to about 3.0 mm/microsecond (the upper limit is purely arbitrary since it represents the framing rate of the camera and its associated lens system), the distance through which the object could travel up to the end of the first recording period can be considered its flight distance prior to recording plus the distance travelled in 20 microseconds (the framing rate of the camera at 5000 rps with the object travelling at the above upper limit). By re-recording the event 200 microseconds later when the event is that much further along the range, a series of pictures is obtained, each frame representing a complete record. The position measurements then determine the accuracy of the velocity determination up to 0.02% (the accuracy with which the elapsed time is measured). Thus a series of 25 individual records can be obtained, giving additional checks on this determination. When this technique is used, no correction is needed for elapsed time since each frame represents a space movement during one complete mirror revolution, which can be monitored to plus or minus one revolution at 5000 rps. The space smear incurred by movement of the object during framing is approximately 0.3 microsecond in duration.

At a distance of 15 feet from the camera, parallax is significant and must be corrected for in making any precise determination. On the assumption that the true distance of the fragment from the scale is precisely 1½ inches, the error due to parallax in the reduction of the record would be approximately 0.8%. The simplest method of correcting for parallax is to use the shadow cast by the fragment. If the light source is placed at a known angle to the target, the distance of the shadow from the pellet can be used to determine the distance of the pellet from the scale. Position can be determined to an accuracy of better than 0.02%.

If the path of the trajectory is precisely known, however, the experiment may be modified so that no correction for parallax is required. In this case, the calibrated scale is placed precisely in the plane of the trajectory and illuminated by a conventional nondestructive high intensity light source. With the camera operating at moderate speeds, a series of still pictures of the scale is photographed over the 25 frames. Thereafter, the scale is removed and a diffusion screen backlighted by an argon flash bomb is set up at a convenient distance behind this plane. The event is then fired as previously described using the rewriting technique. The record thus obtained will have the projectile and scale in the same frame of reference.

Moreover, since there are 25 frames, each frame being a complete record, there will be 25 individual determinations of the average velocity over the distance of travel. In addition, if one handles the records obtained as one would in normal operation without rewriting, the initial 20 microseconds can be used to determine an initial velocity for the first framing interval and a similar velocity determination can be made for the second or rewriting period. The initial and final velocities of the pellets in flight can then be ascertained to an accuracy of 0.1%. This technique can be used to give data concerning angle of flight as well as drag.

It has been stated that the framing camera cannot be used in the study of hypervelocity fragments travelling at high speeds (about 16 mm/microsecond), since the fragments would pass across the normal field of view (12 inches) in 20 microseconds. This field of view does not, however, impose an upper limit for any particular event, since by the use of mirrors two separate portions of the scale can be viewed on a single frame, the frame being split either vertically or horizontally. This would give either two half views of the scale spaced approximately 12 feet apart or two full views of the scales placed one above the other on each frame in a manner similar to the rangefinder principle. The supposition here is that the event can be bracketed by synchronization.

EXPERIMENTAL PROCEDURE

The charge assemblies used in this study were set up in accordance with the procedure used by G. D. Dorough, et al (Ref 1). They consisted of cylindrical charges of high explosive 0.340 inch in diameter and 1.400 inches long, cased in steel cylinders 1.000 inch in diameter and 2.000 inches long with a 0.340-inch central perforation. The projectiles were steel disks 0.340 inch in diameter varying in length from 0.0625 to 0.250 inch (Fig 1, p 6). All the components were cemented into the casing with a minimum of glue to assure good contact between components (Fig 2, p 7). Initiation was by an electric PETN detonator with a tetryl booster, the high explosive under study being adjacent to the steel pellet, whose exposed surface was flush with the base of the case.

The charge assembly was positioned approximately fifteen feet from camera and in a plane normal to its optical axis. The target (scale) and charge assembly were set normal to the axis of the camera by optical means. The assembly was placed so that the projectile in flight would pass approximately 1½ inches in front of the assessment scale. From the measured framing rate together with the geometry of the camera, the elapsed time between frames was determined to 0.1%. Before firing, the assembled charge was arranged as in Figure 3 (p 7), the field of view of the camera being 14 inches.

Figure 6 (p 8) shows schematically the arrangement of the camera and the argon flash bombs as well as the associated firing circuitry. The pulse from the camera is delayed by the first time delay generator so that the total time for the firing of the event and the movement of the pellet into the field of view of the camera should occur during the framing interval of the camera. In like manner, the second time delay generator delays its pulse to permit the argon flash to reach maximum intensity simultaneously with the above. A third time delay generator is used to fire a second argon light source after the rotating mirror has completed one revolution.

For comparative purposes, Figure 4 (p 8) shows the pellet in flight followed by the shadow cast by the argon flash. In like manner, Figure 5 (p 9) shows three pellets fired simultaneously and recorded by the rewriting technique. The spots closest to the center of the record are the shadows cast by the pellets.

REFERENCE

1. G. D. Dorough, H. C. Hornig, J. W. Kury, D. C. Oakley, "The Role of Density and Energy in Plate Acceleration," University of California Radiation Laboratory Report No. 4854 (Secret-Restricted Data)

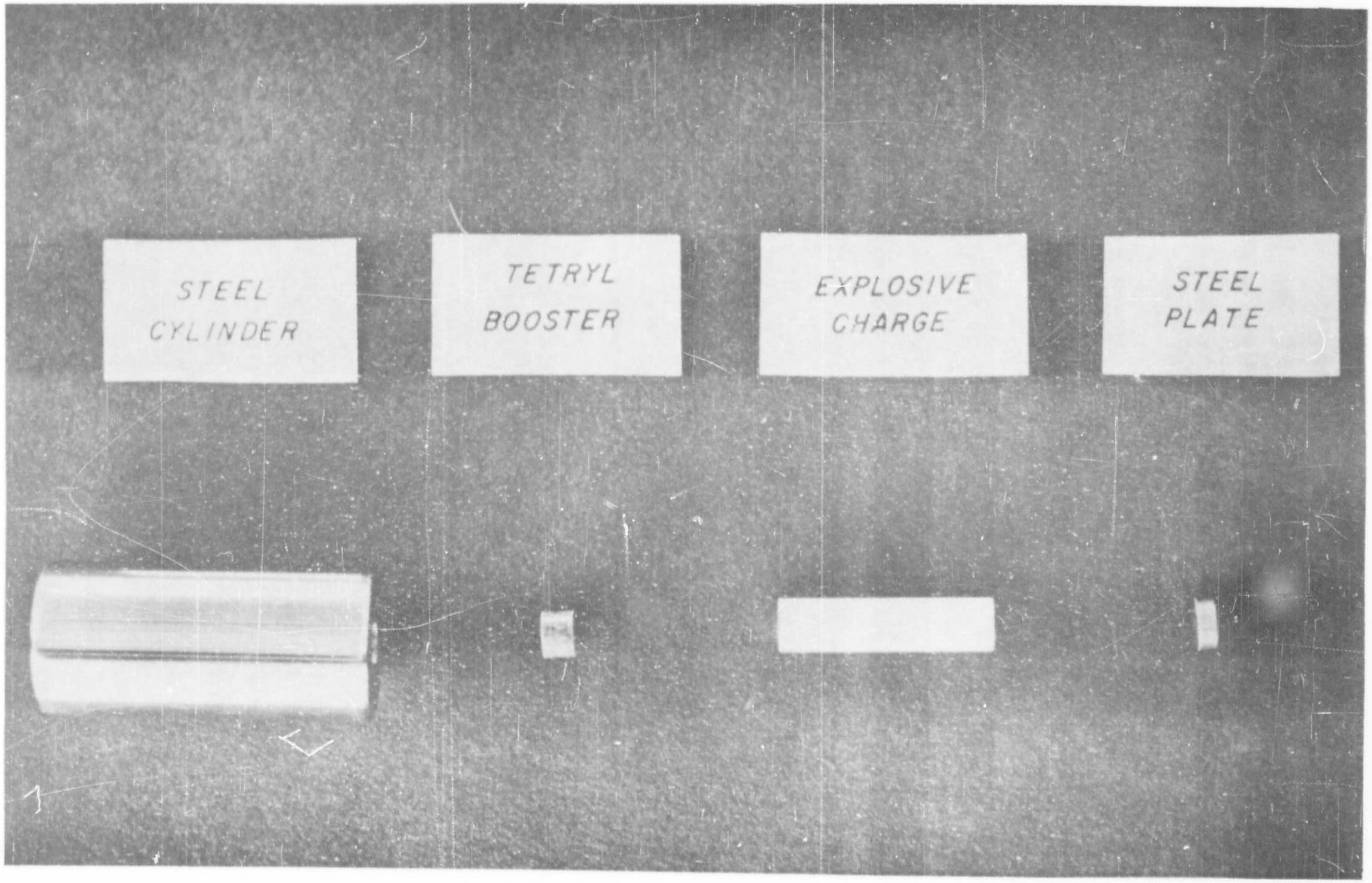

Fig 1 Exploded view of charge assembly.

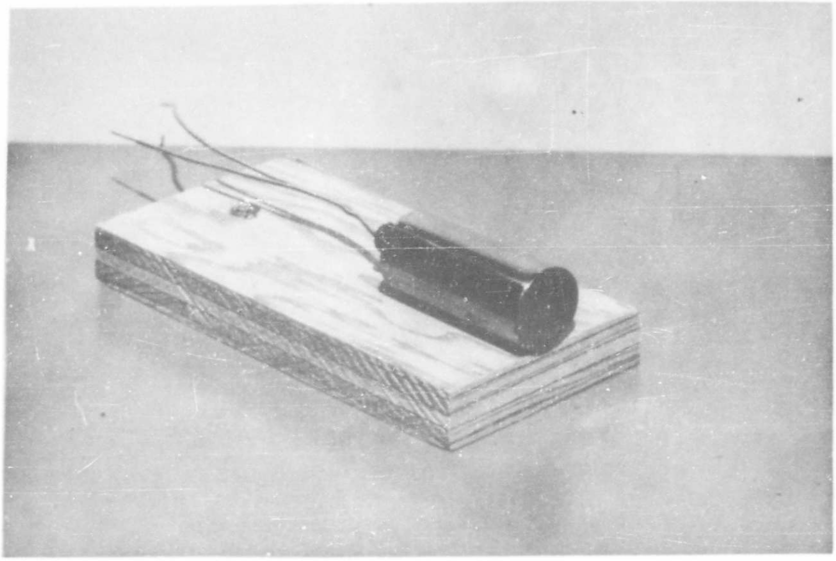

Fig 2 Mounted charge assembly

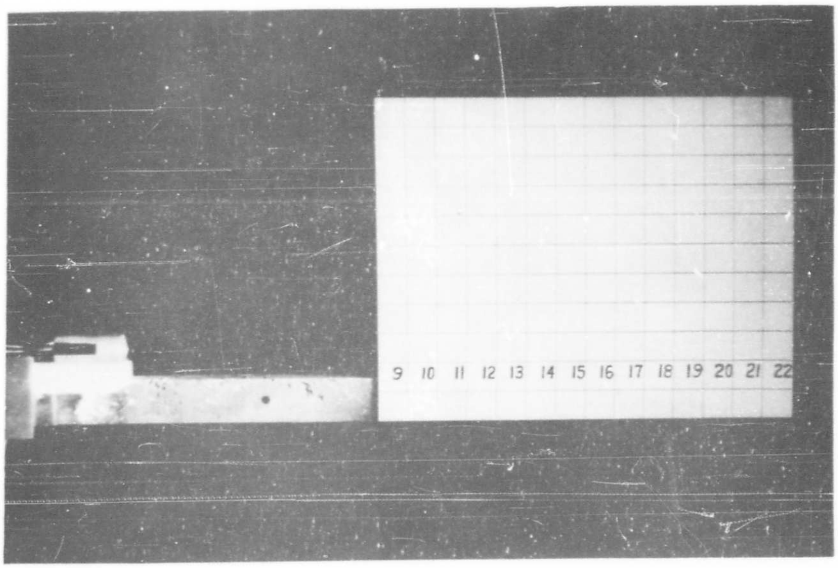

Fig 3 Test setup showing relative arrangement of charge assembly and scale

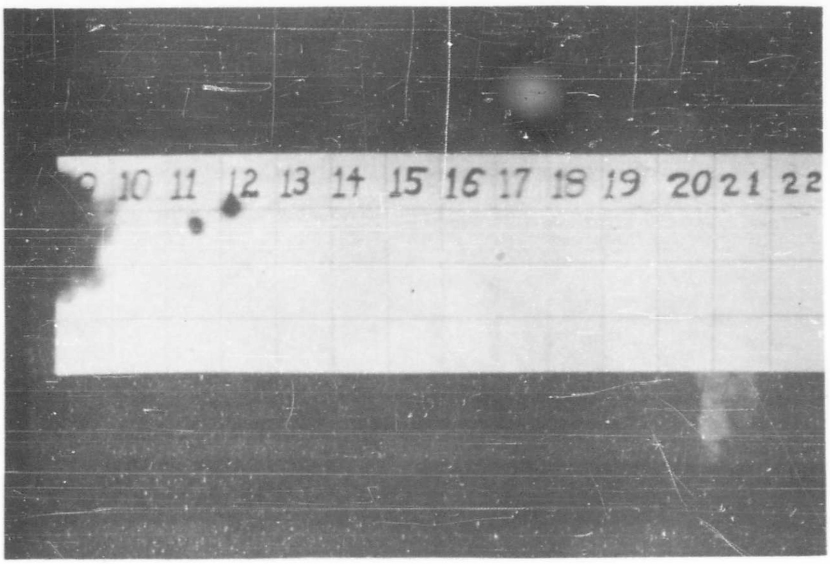

Fig 4 Firing record of single frame with single sweep

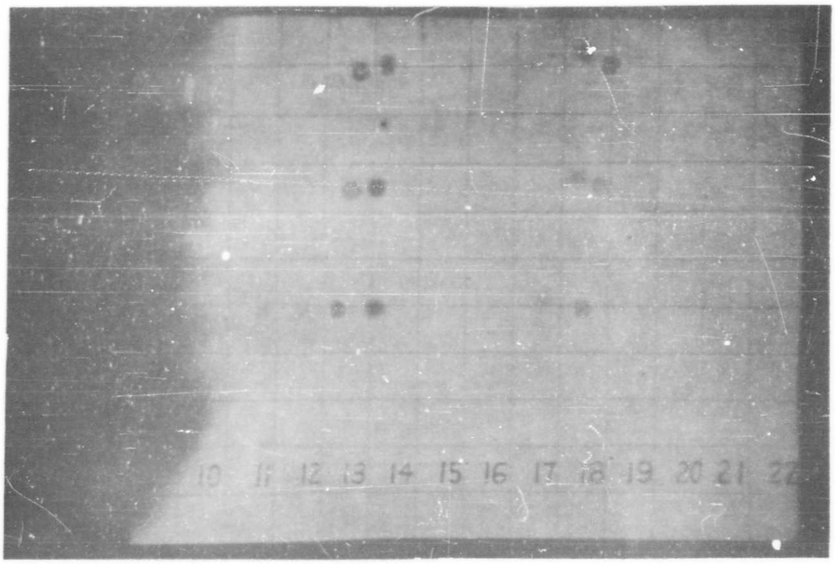

Fig 5 Firing record showing three pellets fired simultaneously using the rewriting technique

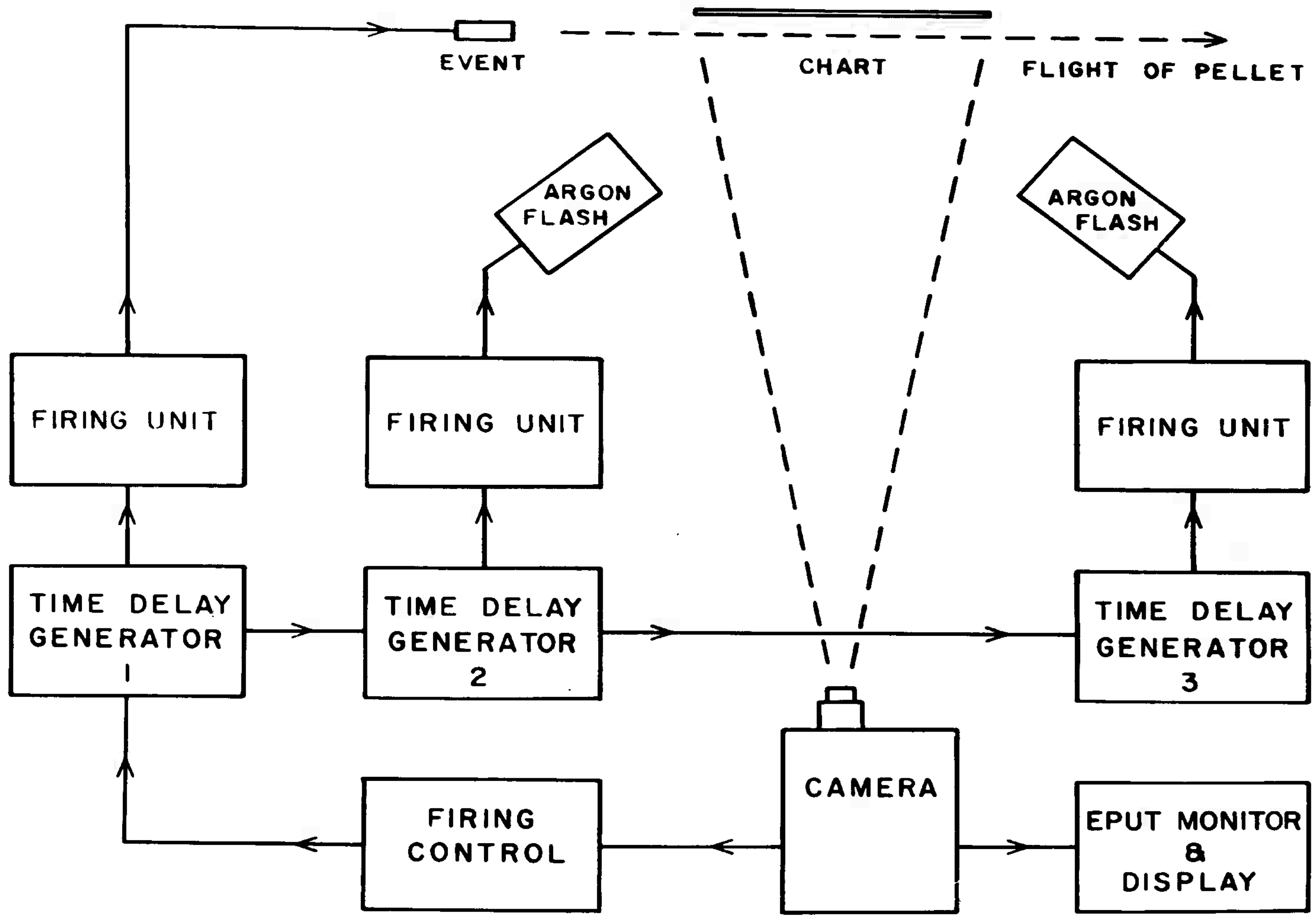

Fig 6 Block diagram showing a typical arrangement of components used in rewriting technique

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